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POSTPRINT

SPALL REPAIR TEST AND EVALUATION (BRIEFING SLIDES)

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14. ABSTRACT

There are two major thrusts of the Spall Repair Technology research effort: 1) evaluation and development of specialized equipment and procedures to expedite and improve the process of preparing spalls for placement of rapid-setting materials and 2) development of tools to predict the performance of spall repairs in service.
A series of experiments were performed using five excavation methods (treatments) on nominal 2-foot-wide 2-foot-long by 4-inch-deep spalls. The type of equipment used were; Jackhammer, Hydraulic breaker on a skid-steer, cold planer, and multiple-blade saw. Production rate, petographic examination, bond strength and performance under simulated aircraft trafficking were use to determine measures of merit. Over a dozen fast setting materials for concrete were evaluated.
The research effort is currently in the laboratory analysis phase to develop performance and sensitivity curves which will be used in determining life expectancy of a specific equipment and material repair.

15. SUBJECT TERMS

pavements, concrete, maintenance, repair, spall, fast setting, equipment for spall repair, cold planer, multiple-blade saw

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Spalling describes cracking, breaking, chipping, or fraying of a concrete slab near a joint or crack. Spalls may be partial or full depth. In the case of both full- and partial-depth spalls, foreign object debris (FOD) may be generated, and the rough surfaces at the spall may damage aircraft tires. Full-depth spalls reduce the structural capacity of the slab and exacerbate fatigue failure under repeated loading.

Spall repairs at expeditionary locations have failed sooner than expected based upon load test studies. Many of these repairs involve large, relatively non-uniformly shaped repairs that may be placed back into service within a few hours after placement. The service life of a spall repair is dependent on many factors such as the construction quality, repair material properties, and loading conditions. The most important factor is often the time required to construct a durable repair. Expedient repairs are made when time, equipment, and/or manpower is not available to install a permanent repair. As with any quick fix, there is often a trade off between expediency and quality. Rapid repairs extend the life of a pavement using more forgiving methods than those used in traditional repairs, but durability and long-term performance may suffer.

Because spall repair service life is influenced by many factors, Air Force civil engineers and airfield managers are often forced to make airfield maintenance decisions with only limited information on the expected performance of spall repairs. Spall repair performance curves that consider these factors would greatly assist airfield management decision makers in determining what types of repairs to make and when to make them.

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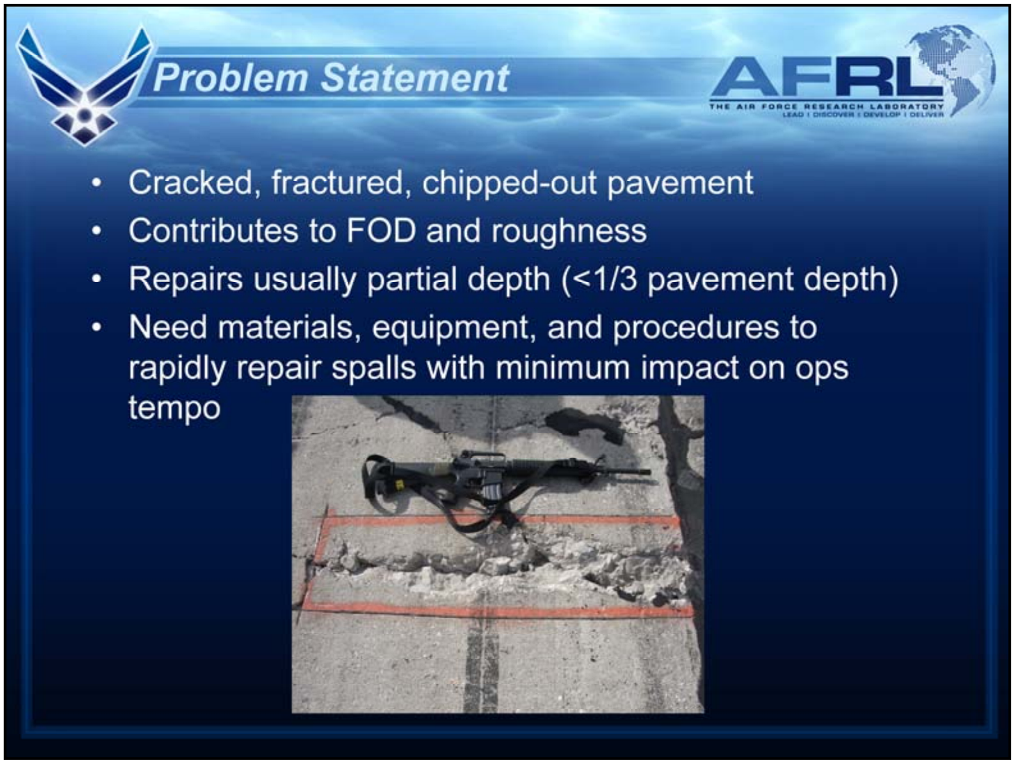

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Spall repairs at expeditionary locations have failed sooner than expected based upon load test studies. Many of these repairs involve large, relatively non-uniformly shaped repairs that are loaded within a few hours after placement. The service life of a spall repair is dependent on many factors such as the construction quality, repair material properties, and loading conditions. The most important factor is often the time required to construct a durable repair.

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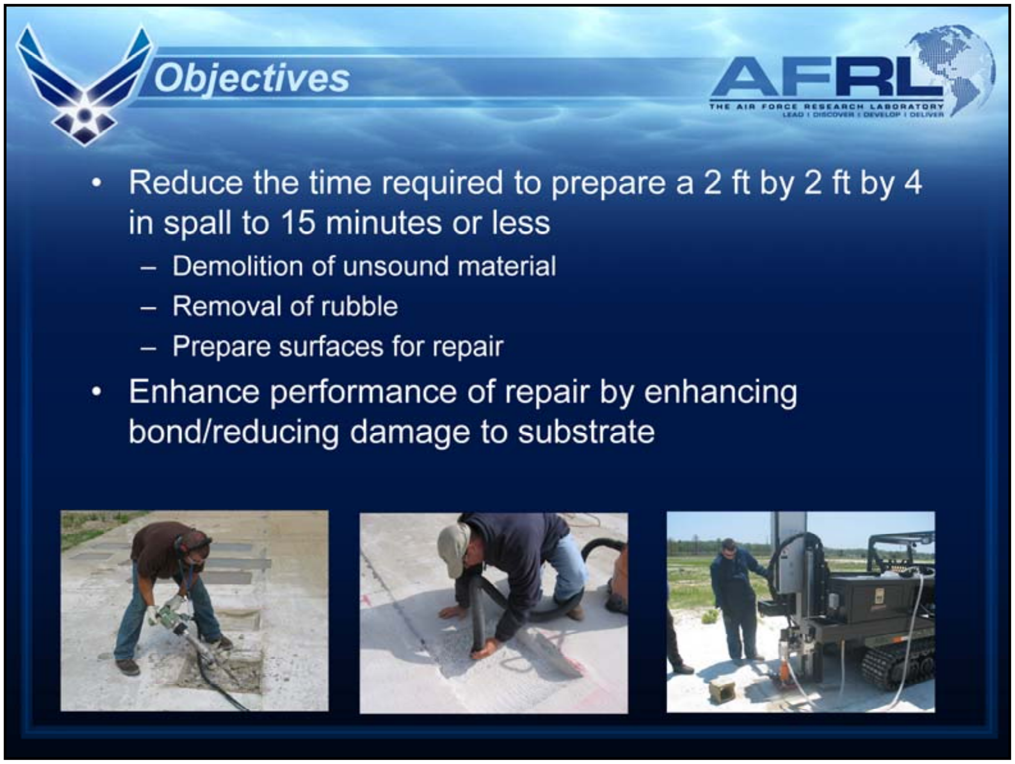
The objectives of this research are to adopt optimal spall preparation techniques and equipment, select optimal spall repair materials, and to predict spall repair performance. Because airfield operations are negatively impacted during the process of performing spall repairs, the time required to perform spall repairs is critical to maintaining the flying mission. The impact of the spall repair process on aircraft operations can vary by degree, ranging from an inconvenience to the complete suspension of flight operations.

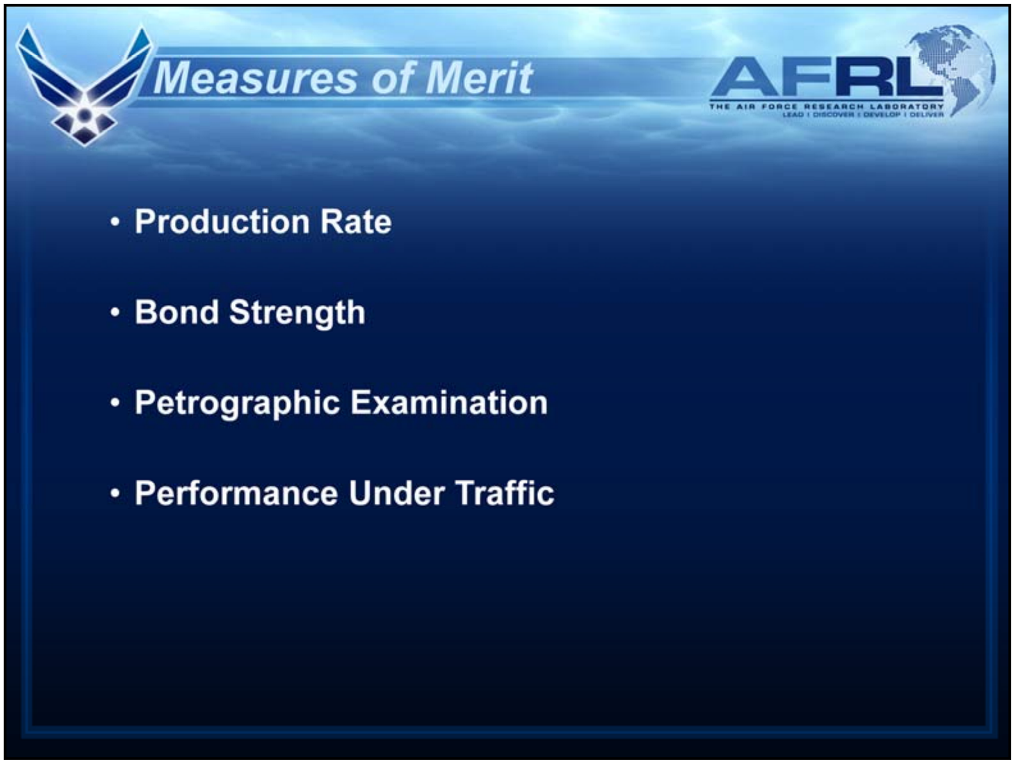
Spall Repair Equipment



The objective of this research was to develop one or more methods that will allow field personnel to excavate and prepare a 2-foot-wide by 2-foot-long by 4-inch-deep spall for placement of a rapid-setting repair material in fifteen minutes or less. A secondary objective was to correlate various excavation methods with a relative life expectancy of the repair.

A series of experiments were performed using five excavation methods (treatments) on nominal 2-foot-wide 2-foot-long by 4-inch-deep spalls. After excavation, core samples were extracted from each treatment, and petrographic examinations were performed. Final preparation for each method consisted of pressure washing and excess water removal leaving the excavation clean and surface damp. The spalls were repaired with the same self-leveling cementitious repair material. A series of 2-inch-diameter cores were cut through the repair material and into the substrate. The cores were used to perform in-situ tensile pull-off tests to evaluate the bond between the repair material and the substrate. Also, a series of 4-inch diameters cores were cut, and direct shear tests were performed on the repair material/substrate interface. Finally, all spalls were trafficked for 1,500 passes using an F-15E load cart.

The common method to remove material from a spall repair is to use a portable pneumatic jackhammer as shown in Figure 6. ACI RAP Bulletin 7 recommends that jackhammers larger than 30 lbs not be used, because they may cause damage to the surrounding concrete. For this experiment a 2 ft by 2 ft area was cut using a walk-behind saw to a depth of approximately 4 inches. The concrete inside the cut was removed with a 30-lb pneumatic jackhammer. A nail-point breaker tip was used to break up the concrete, and a spade tip was used to dress the repair area. Final clean up was performed by shoveling the rubble in to a loader bucket, sweeping around the hole, and vacuuming the fines from the hole.



The spall repair equipment and methods will be evaluated on the measures of merit described below.

Production Rate

Two measures of production rate were employed: 1) excavation production rate and 2) total production rate. The *excavation production rate* is defined as the time required to excavate using the equipment and method evaluated. The *total production rate* is defined as the time required excavating 1 cu ft of spall, removing rubble, and preparing the spall repair for placement of rapid-setting repair material.

Petrographic Examination

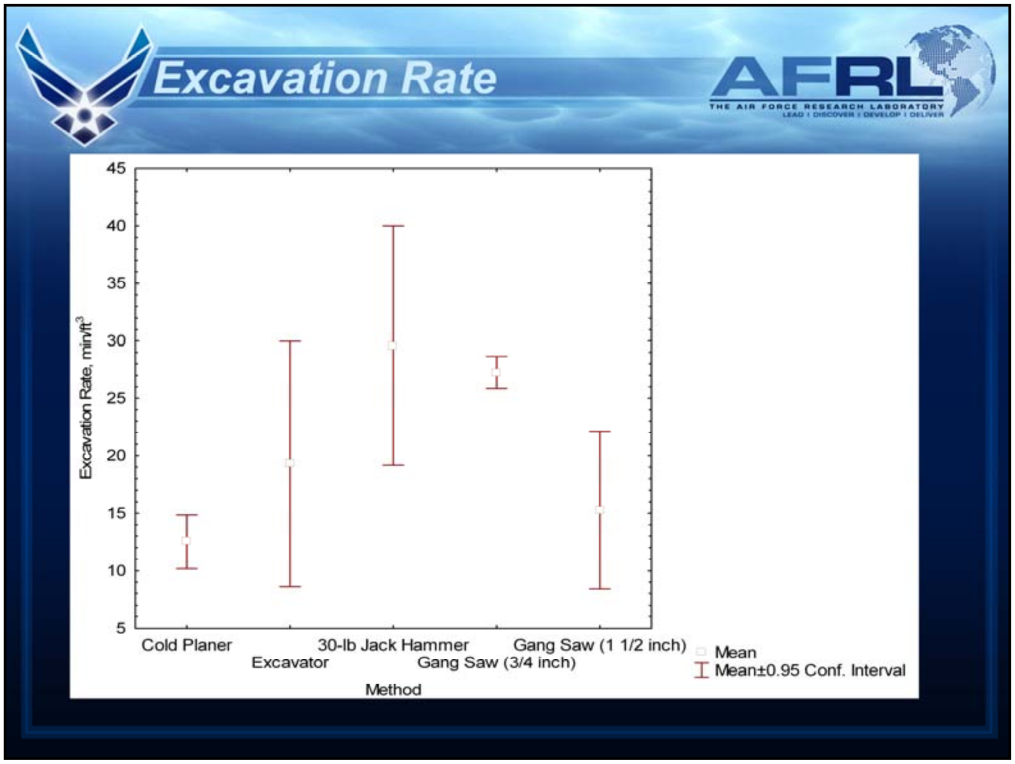
One 6-inch-diameter core sample was removed from the interior of one excavation from each treatment (leaving two excavations from each treatment intact). Additionally, one 6-inch-diameter core was extracted from the undamaged concrete around the excavation areas as a control.

Bond Strength

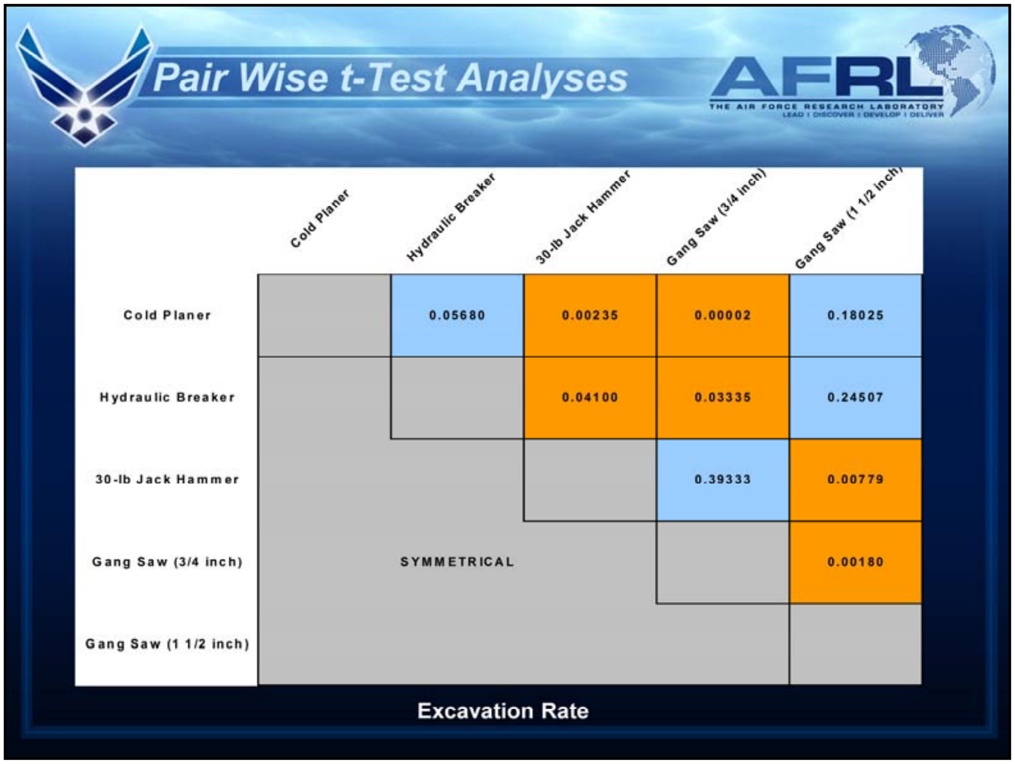
Bond strength was evaluated by two methods: 1) in-situ tensile pull-off test and 2) a direct shear bond test. The in-situ tensile pull off test is described by the International Concrete Repair Guideline No. 03739.

Performance under Simulated Aircraft Trafficking

The spall repairs were evaluated under 1500 passes of AFRL's F-15E load cart. A single-lane trafficking pattern was used in which all tire loads were applied to the center of the spall repair area.



The data were used to develop the plot shown here, where the mean value of excavation rate is represented by the small squares, and the whisker bars represent ±95 percent confidence intervals on the mean. There was considerable scatter in the data, as indicated by the length of the confidence intervals. Comparing only mean values of excavation rate revealed that the 30-lb jack hammer, the typical method of excavating spall repairs, was the least efficient method. The most efficient method was the cold planer, which, on average, was approximately 58 percent more efficient than the jack hammer. The second most efficient method was the excavator, followed by gang saw with spacing at 1½ inches and ¾ inch.

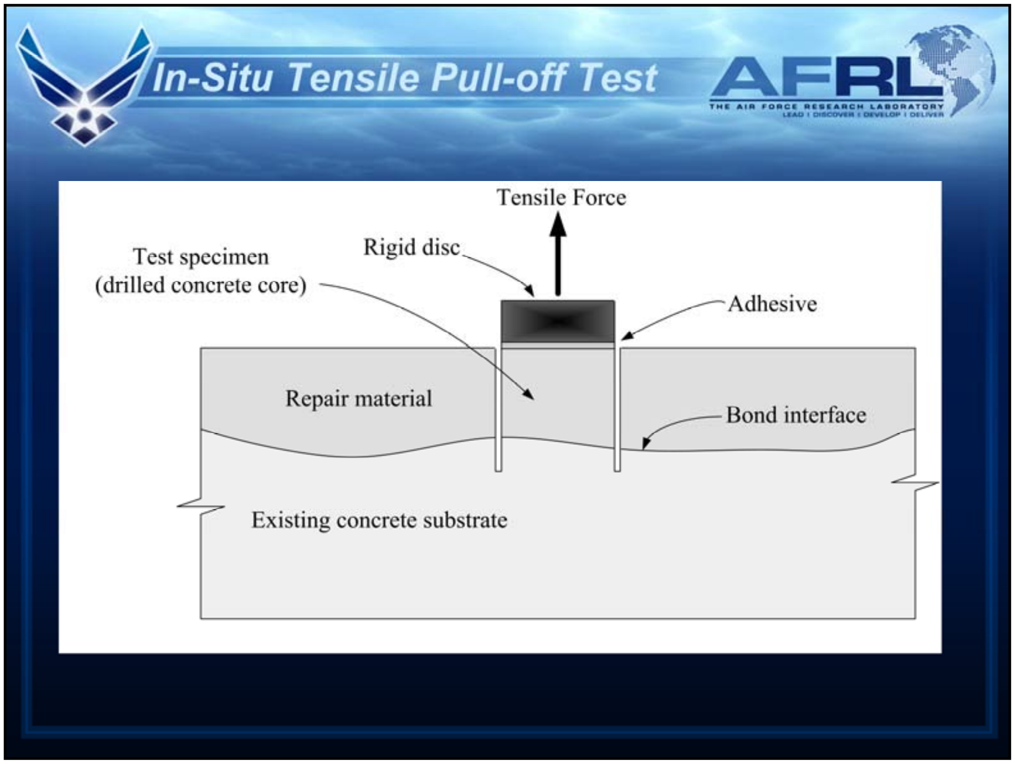


Pair Wise t-Test Analyses

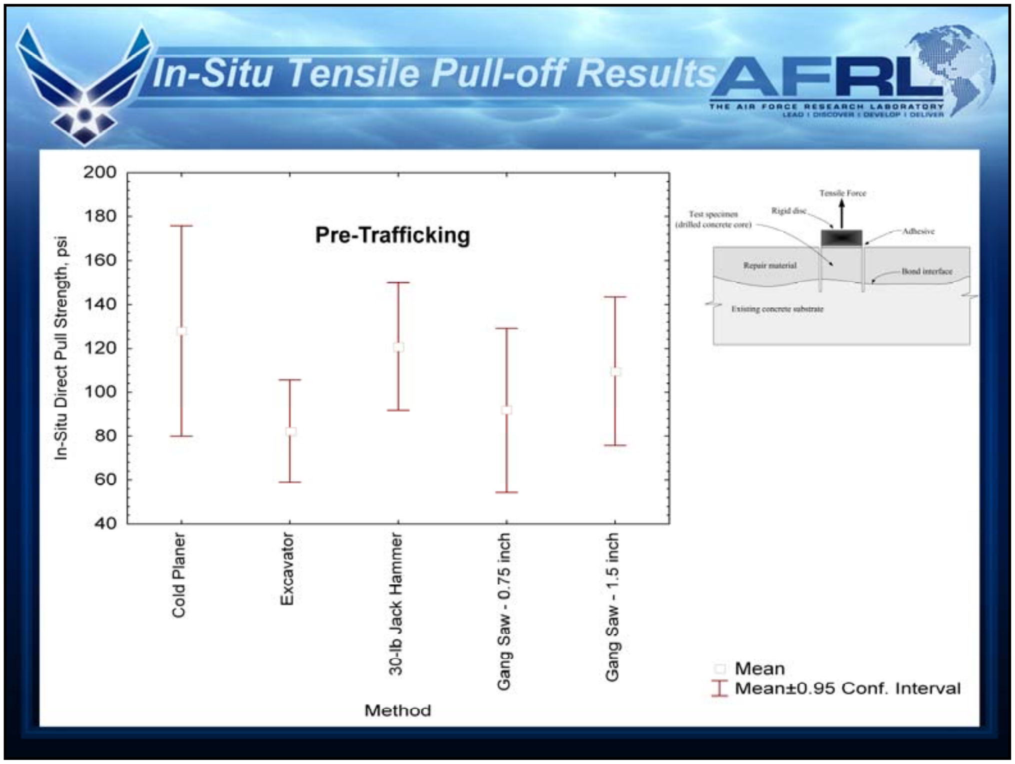
	Cold Planer	Hydraulic Breaker	30-lb Jack Hammer	Gang Saw (3/4 inch)	Gang Saw (1 1/2 inch)
Cold Planer		0.05680	0.00235	0.00002	0.18025
Hydraulic Breaker			0.04100	0.03335	0.24507
30-lb Jack Hammer				0.39333	0.00779
Gang Saw (3/4 inch)	SYMMETRICAL				0.00180
Gang Saw (1 1/2 inch)					

Excavation Rate

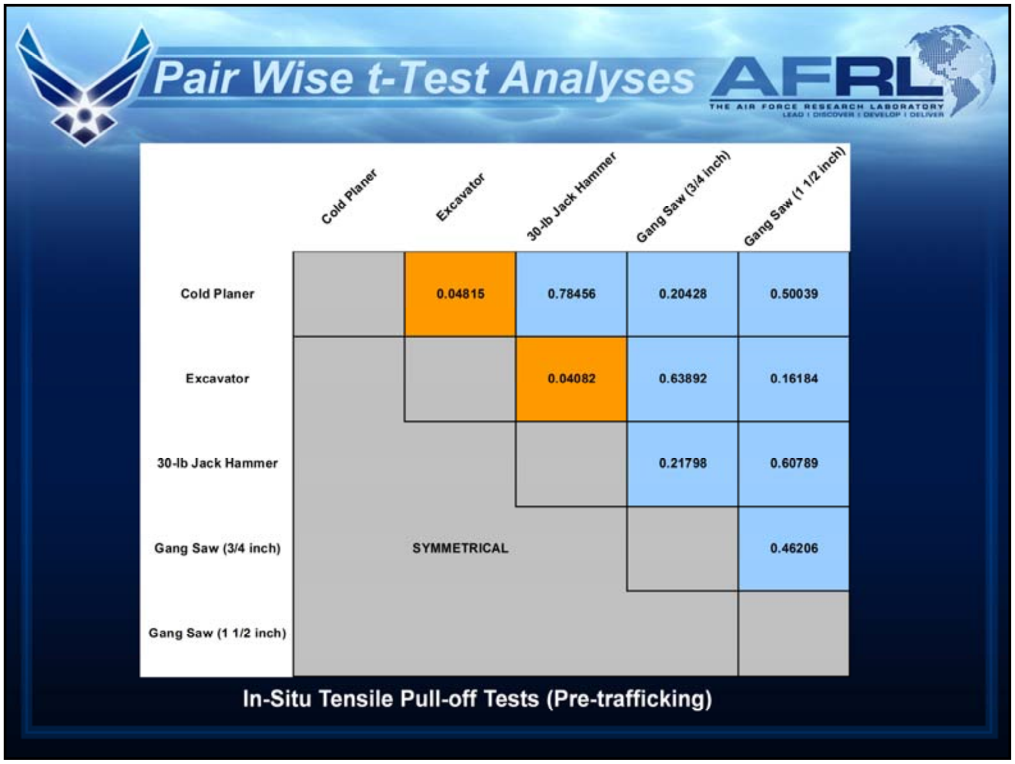
A pair wise t-test procedure was used to compare the means to determine if the observed differences in the mean value were statistically significant given the large scatter of the data. The results of these tests are presented in Figure 17. The value tabulated in each cell is the P value that resulted from the pair wise t-test for the combination of treatments represented by the cell. A lower P value indicates a greater significance. In Figure 17, any cell with a P value less than 0.05 is highlighted in orange. This indicates that there is a greater than 95 percent probability that the differences observed between the two methods are statistically significant. Using these analyses, we observe that the production rates for the 30-lb jack hammer are statistically different from those of the cold planer, hydraulic breaker, and the gang saw at 1½-inch spacing. Comparing with Figure 16, we observe that each of these methods is a significant improvement in production rate over the 30-lb jack hammer.



The in-situ tensile pull off test is described by the International Concrete Repair Guideline No. 03739. This protocol, which is based upon ASTM D4541, allows the user to evaluate the in-situ tensile bond strength. A core bit was used to drill through the repair material and into the substrate. A rigid disc was attached to the top of the drilled core using a high-strength adhesive. A testing device applied a tensile force to the rigid disc at a constant rate until fracture occured. The tensile force and location of the fracture (at the adhesive, at the bond interface, within the repair material, or within the substrate) were recorded.



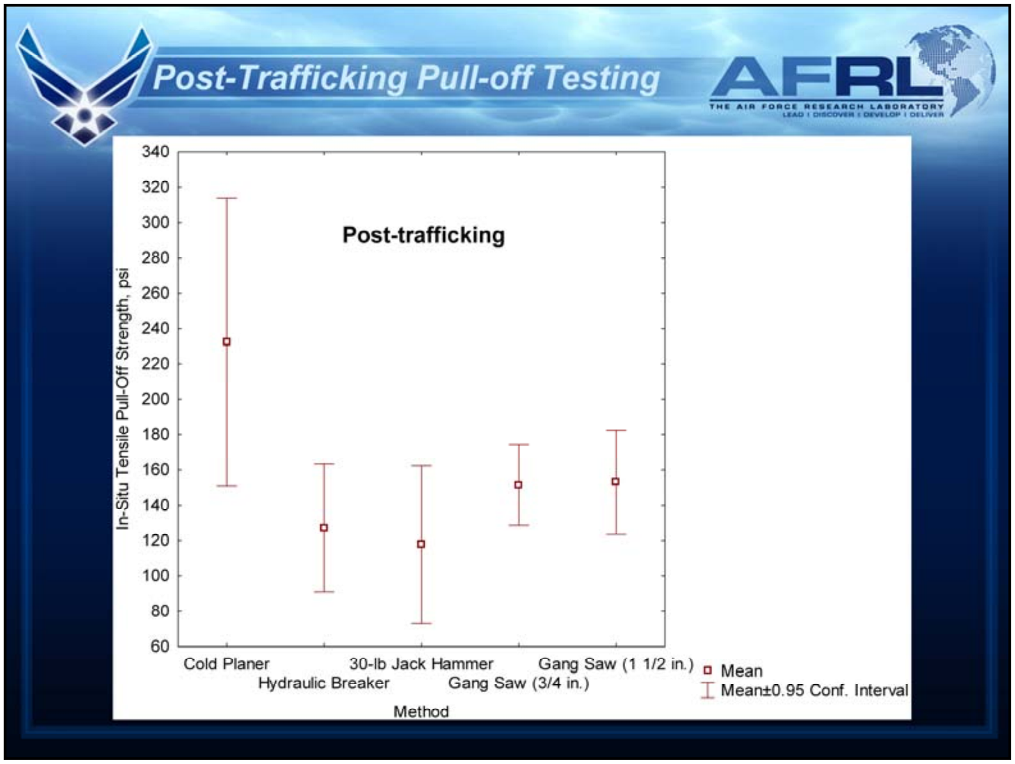
The greatest observed mean pull-off strength was for the cold planer, followed, in order, by the jack hammer, gang saw at 1½ inches spacing, gang saw at ¾ inch spacing, and finally the hydraulic breaker. However, the scatter in the data is quite large, and statistical analysis was required to evaluate the significance in the observed means.



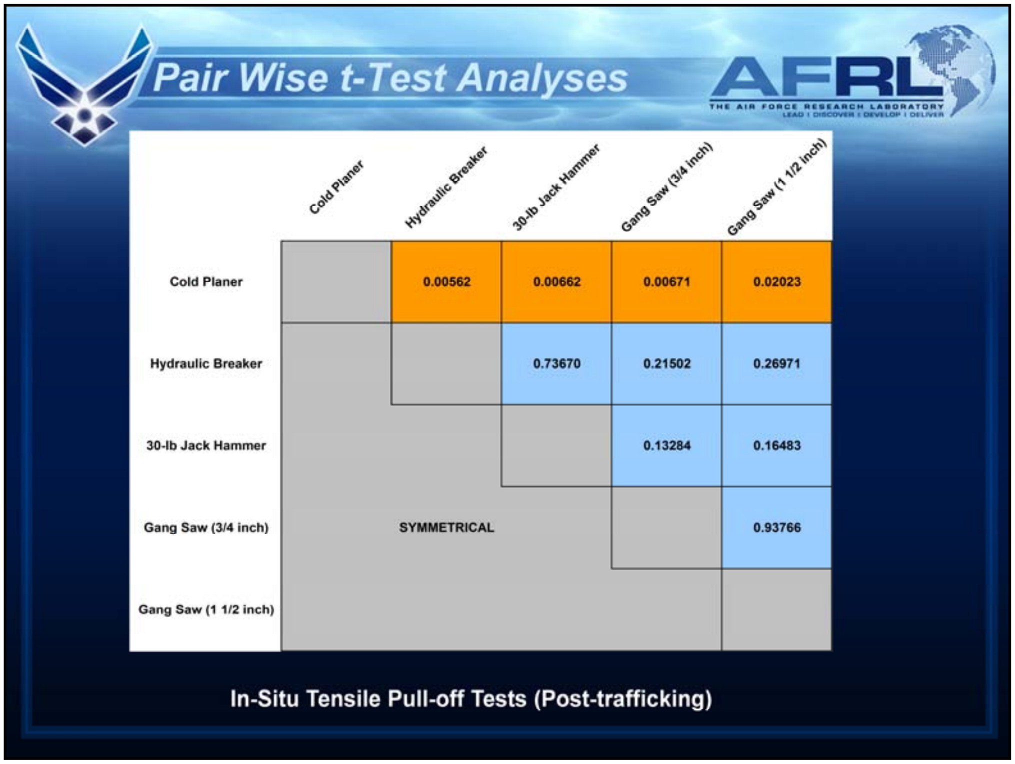
	Cold Planer	Excavator	30-lb Jack Hammer	Gang Saw (3/4 inch)	Gang Saw (1 1/2 inch)
Cold Planer		0.04815	0.78456	0.20428	0.50039
Excavator			0.04082	0.63892	0.16184
30-lb Jack Hammer				0.21798	0.60789
Gang Saw (3/4 inch)		SYMMETRICAL			0.46206
Gang Saw (1 1/2 inch)					

Pair wise t-tests were conducted on each of the observed treatments, and these results are summarized here. The value tabulated in each cell is the P value that resulted from the pair wise t-test for the combination of treatments represented by the cell. A lower P value indicates a greater significance, and cells with a P value less than 0.05 are highlighted in orange. This indicates that there is a greater than 95 percent probability that the differences observed between the two methods are statistically significant. For these experiments, the t-tests indicated that only the differences in the means between the hydraulic breaker and cold planer and hydraulic breaker and jack hammer were statistically significant at the 95 percent confidence level, and one cannot statistically distinguish between the means of the other treatments at the 95 percent confidence level.

Each of the replicates and treatments were subjected 1500 passes of simulated F-15E tire traffic using AFRL's F-15 load cart. During the conduct of the testing, no cracking, spalling, or any other type FOD-creating distresses were observed. During the testing, the spall repairs were sounded with a small hammer in an attempt to detect delamination or debonding of the repair from the substrate. As the testing progressed, the technicians observed a hollow-sounding thud from the hammer blows, which interpreted as delamination. However, post-trafficking evaluations revealed this not to be the case, as the spall repair material remained bonded to the substrate.



For all treatments the pull-off strength was non-zero, indicating that the bond was not broken during the trafficking of the spall repairs. The highest post-trafficking in-situ bond strength was observed for the cold planer, with the other methods having bond strengths approximately one-half that of the cold planer.



	Cold Planer	Hydraulic Breaker	30-lb Jack Hammer	Gang Saw (3/4 inch)	Gang Saw (1 1/2 inch)
Cold Planer		0.00562	0.00662	0.00671	0.02023
Hydraulic Breaker			0.73670	0.21502	0.26971
30-lb Jack Hammer				0.13284	0.16483
Gang Saw (3/4 inch)		SYMMETRICAL			0.93766
Gang Saw (1 1/2 inch)					

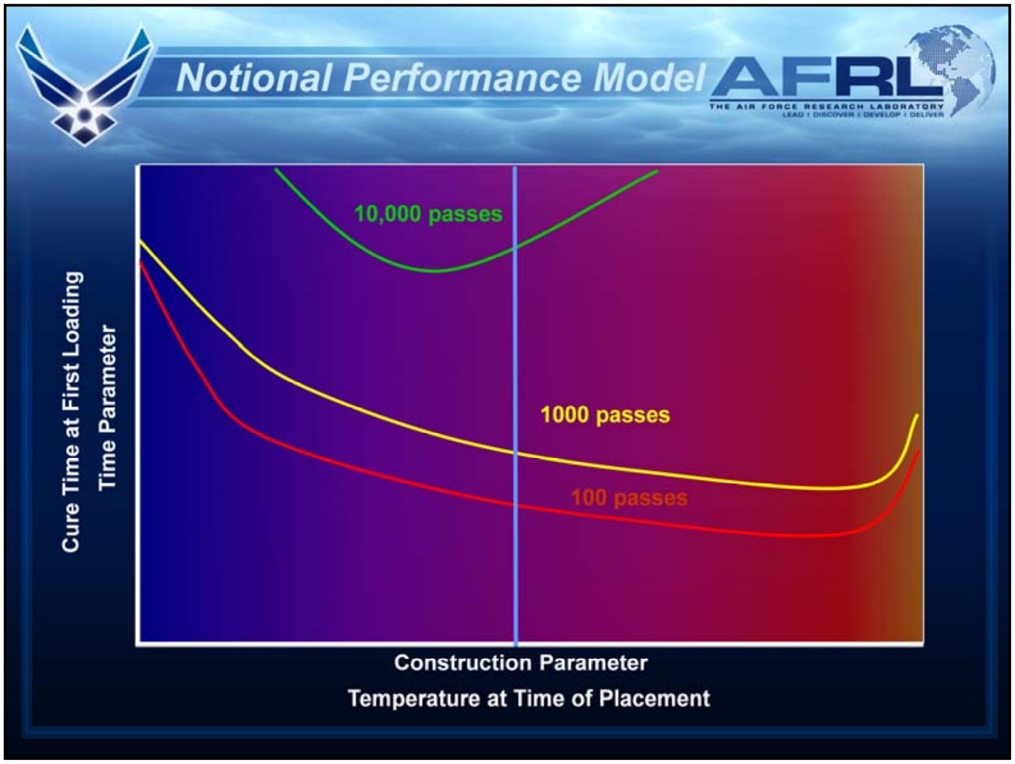
The observed difference in mean value between the cold planer all the other four methods were statistically significant at the 95 percent confidence level.

Bottom Line

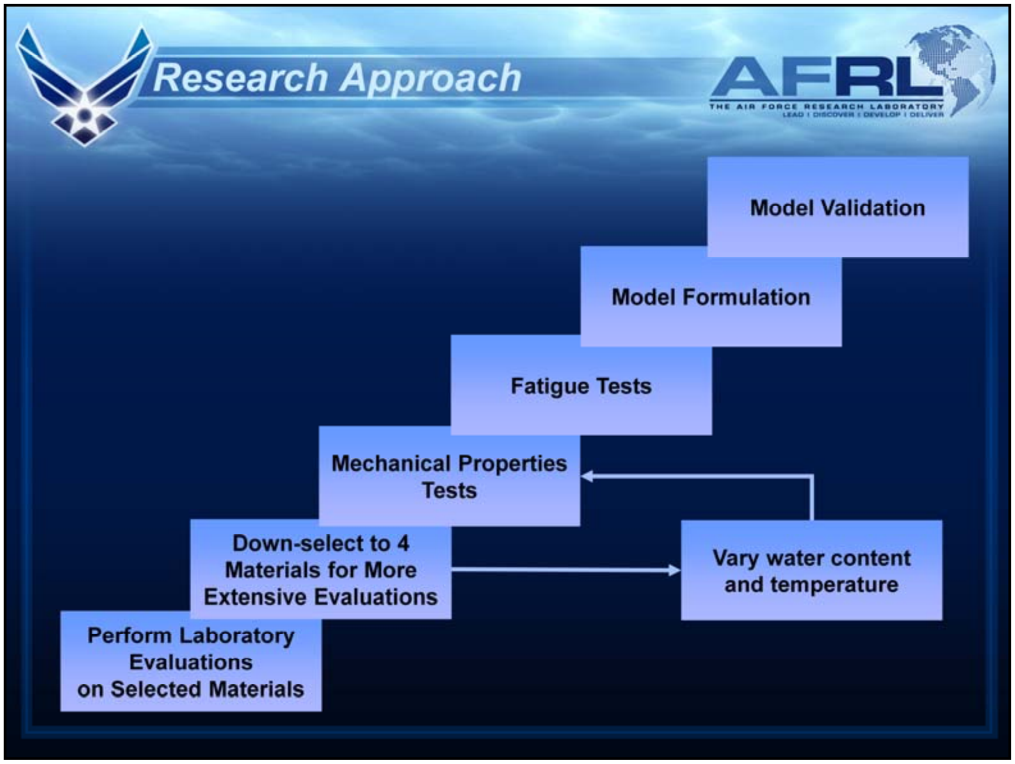
1. Both new methods of preparing a spall for repair using rapid set materials are more efficient than conventional methods by up to 50%.
2. The cold planer method was found to provide superior bond after 1500 passes of the F-15. Therefore, it is expected to provide superior field performance compared to conventional methods and the gang-saw method.

Spall Repair Performance Curves

The objective of this project is to develop spall repair performance curves based on factors that influence their service life to aid Air Force civil engineers and airfield managers. An Engineering Technical Letter (ETL) will be developed that includes spall repair performance curves based upon material strength development, aircraft type, and repair location (edge or corner repair).



This slide illustrates what a notional performance model might look like for a spall repair material. Spall repair performance will depend upon a construction parameters and time parameters. An example of a construction parameter would be the temperature at time of placement. An example of a time parameter would be the cure time a first loading. The resulting performance model would allow users to estimate the number of passes of a selected aircraft of interest before a limit (unsatisfactory performance) state would be achieved for the repair.

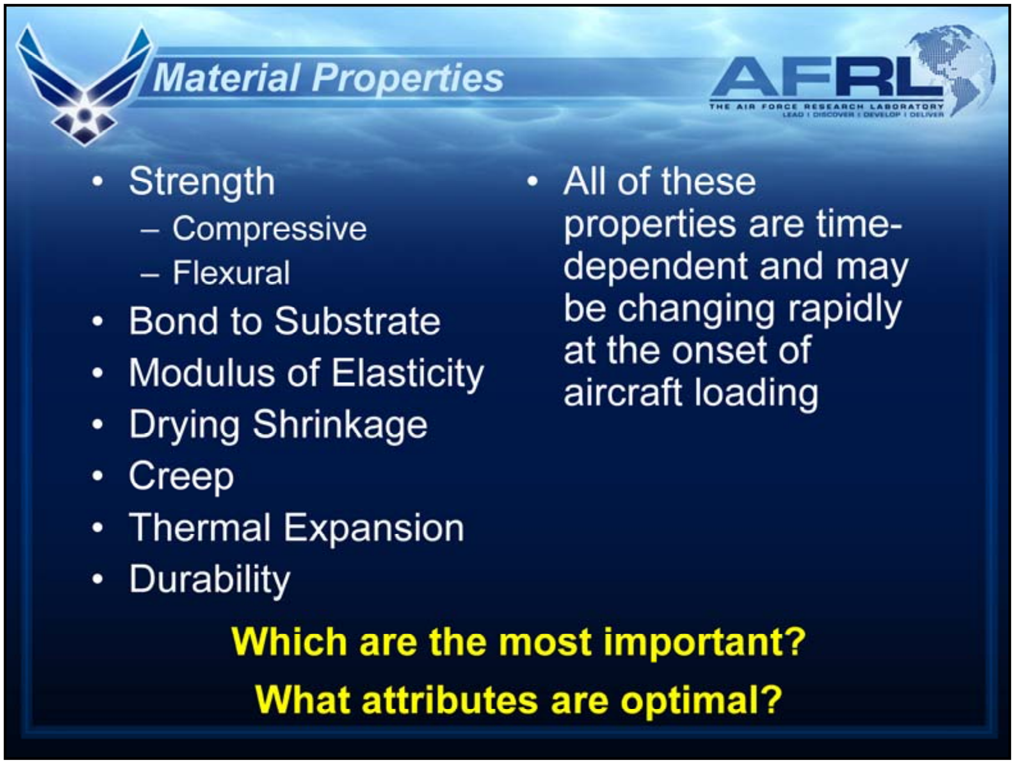


Early strength development was determined for all materials using manufacturer's recommendations and at room temperature. Four materials that represented a wide range of performance were selected for further study. Additional tests included compressive, flexural and bond strength development at varying water contents and temperatures. Finally, the affect of early loading conditions on bond strength development was evaluated.

Fatigue tests are being conducted on four representative spall repair materials. Tests were conducted to simulate joint and interior loading where a spall repair is primarily in compression, and corner loading where a spall repair is primarily in tension. Early loading conditions were also simulated.

Service life predictions for concrete pavements are typically determined by fatigue analysis. The most common fatigue models estimate the number of allowable load repetitions for a given ratio of critical stress caused by the application of wheel loads. Accumulation of fatigue damage determines the service life of the pavement. Performance curves were based upon observations from the fatigue tests, strength development of the materials, and existing fatigue curves.

It is anticipated that up to three materials will be selected that generally represent the performance of the repair materials. A C-17 wheel load (138 psi tire pressure), simulated with a load cart, will be used to traffic edge and corner spall repairs at 1.5 hours and 3 hours after mixing. Load cart tests will be used to validate the performance curves and expedient field tests.



The engineering properties of repair materials vary widely from material to material. Finding an ideal material is difficult, because while one material may excel in certain respects, it may be deficient in other respects. Mechanical properties reveal a material's elastic and inelastic behavior when a force is applied. It is usually unnecessary for the repair material to have mechanical properties in excess of the substrate. However, if some of the mechanical properties are vastly different than those of the substrate, problems may ensue. For example, large differences in stiffness between the repair material and substrate may lead to stress concentrations which break the bond at the interface between the repair and substrate materials.

Hypotheses

Property	Desired Attribute
Shrinkage	Low (Limit volume change)
Bond Strength	High (Repair/substrate act as unit)
Coeef. of Thermal Expansion	Close in magnitude to substrate material
Modulus of Elasticity	Moderate to Low – Higher modulus values result in higher stresses when volume change is restrained – Too low and material will undergo excessive deformation under mechanical loading
Flexural Strength	Moderate (Fatigue Resistance)
Compressive Strength	Only important as it impacts flexural strength and elastic modulus

Important mechanical properties include the following:

Elasticity – the ability of a material to regain its size and shape after removal of a load

Modulus of elasticity – the stiffness of a material measured as the ratio of the normal stress to normal strain in the elastic regime.

Creep – time-dependent deformation due to sustained load

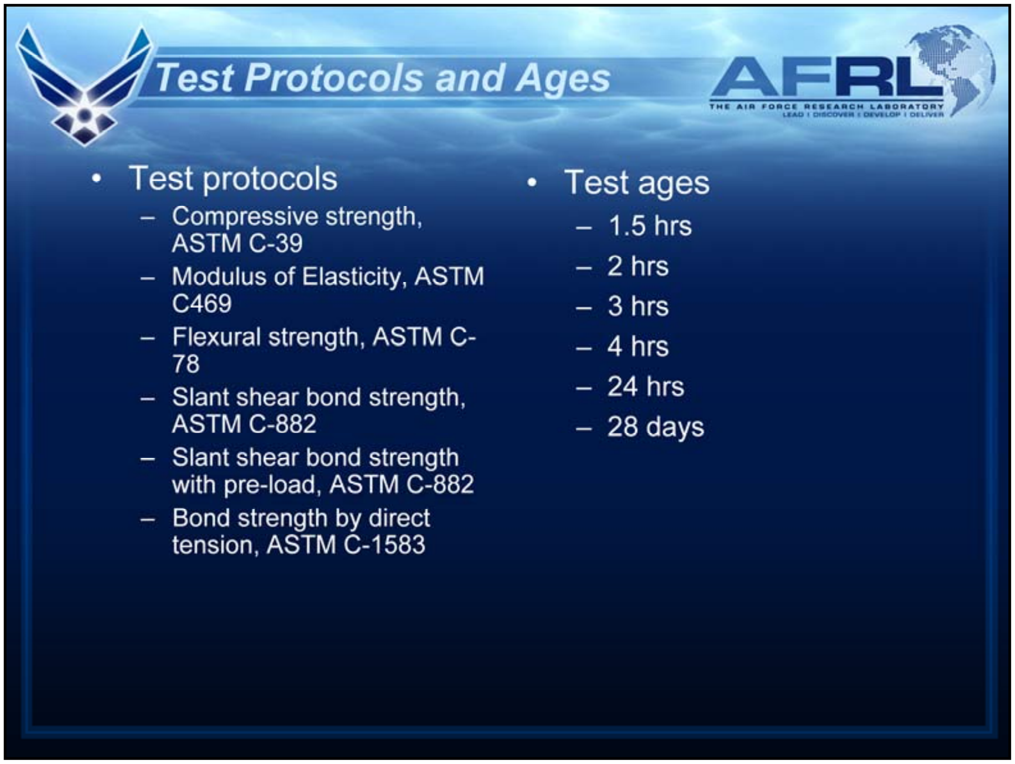
Bond strength – the resistance to separation between the repair material and the substrate.

Compressive strength – the resistance of a material to compressive load.

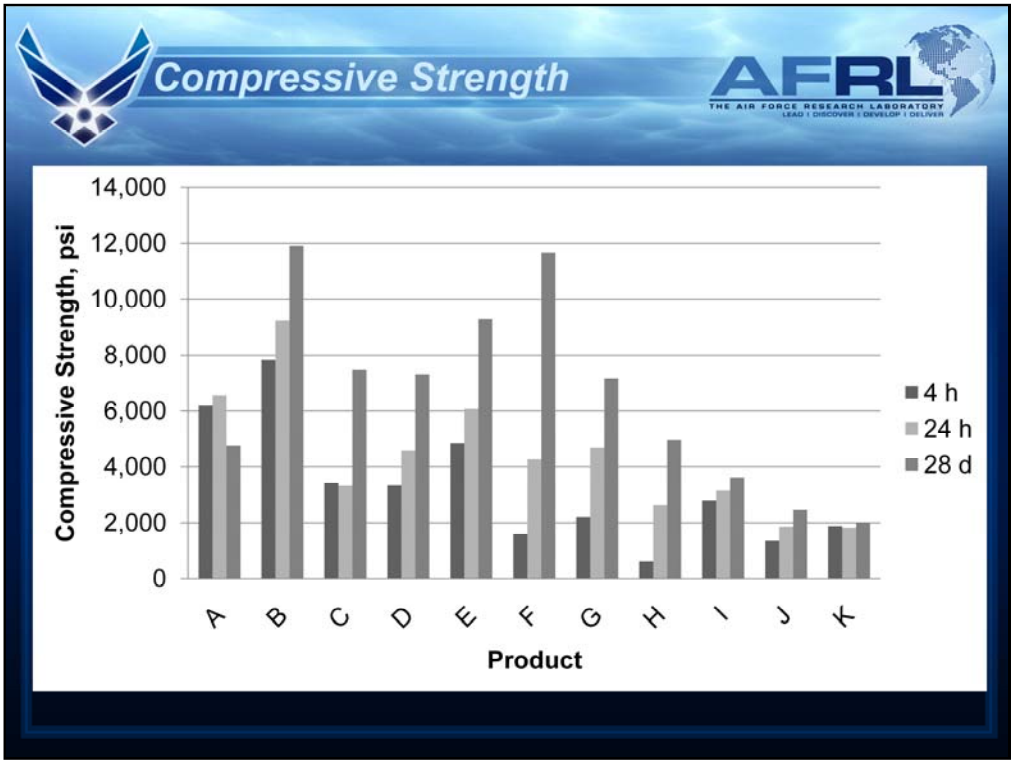
Tensile strength – the resistance of a material to tensile load

Modulus of rupture or flexural strength – the resistance of a material to bending. This property is related to tensile strength.

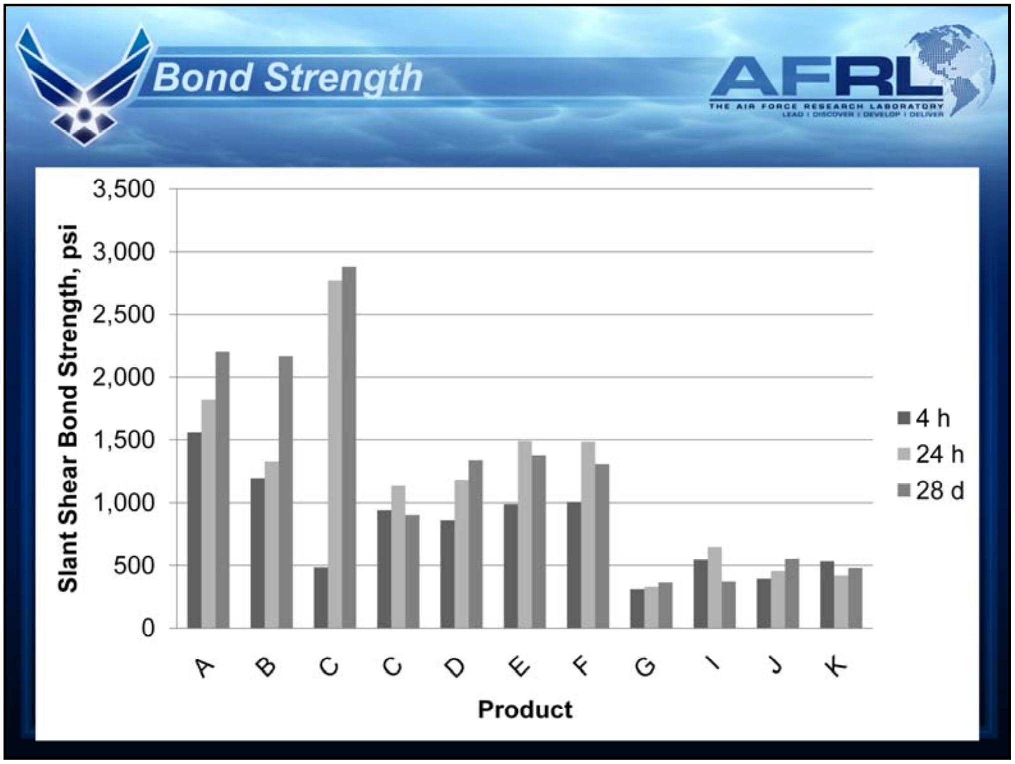
Coefficient of thermal expansion – the change in linear dimension of a material with change in temperature.

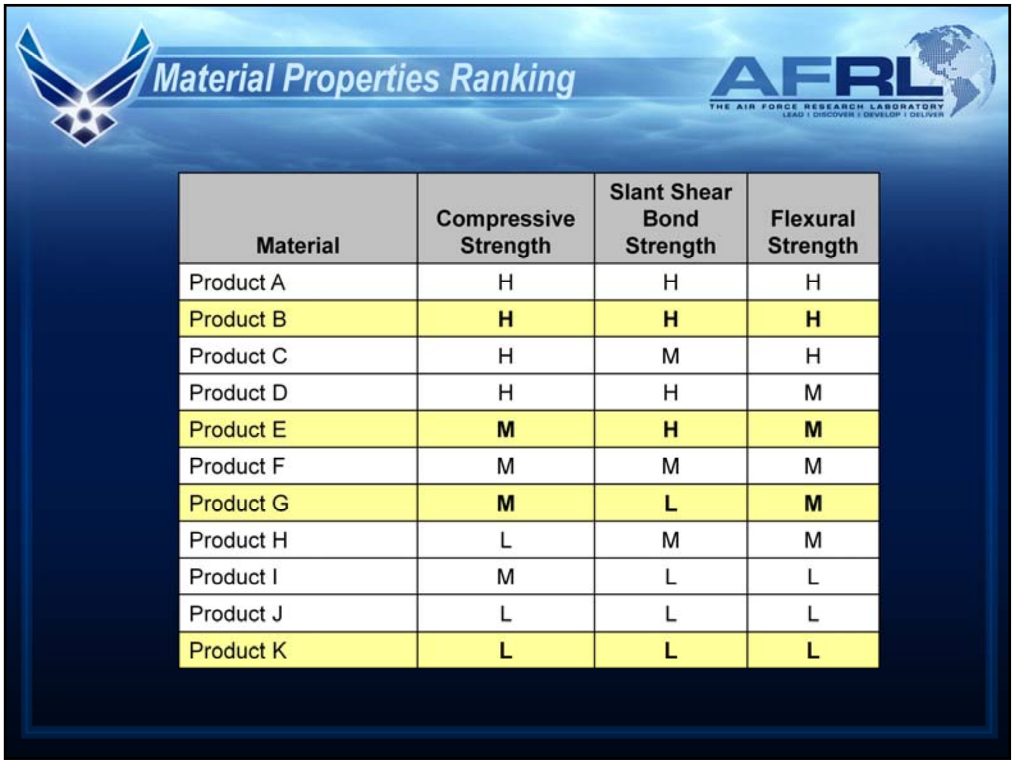


Early strength development was determined for all materials using manufacturer's recommendations and at room temperature. Four materials that represented a wide range of performance were selected for further study. Additional tests included compressive, flexural and bond strength development at varying water contents and temperatures. Finally, the affect of early loading conditions on bond strength development was evaluated. Test intervals were measured from the start of mixing and were conducted at 1.5 hours, 2 hours, 3 hours, 4 hours, 24 hours and 28 days. Three samples were tested at each time interval.



Rapid Set DOT Mix, SikaQuick 2500, Premium Patch and HD-50 Rapid Set gained greater than 2,500 psi compressive strength in 2 hours or less. These materials represent achieved the most rapid compressive strength gain. Pave Patch-3000, PaveMend TR and PaveMend 15 gained strength the slowest and did not achieve more than 2,700 psi in 24 hours.


Bond Strength
AFRL
THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER
Slant Shear Bond Strength, psi
3,500
3,000
2,500
2,000
1,500
1,000
500
0
A
B
C
C
D
E
F
G
I
J
K
Product
4 h
24 h
28 d



Material	Compressive Strength	Slant Shear Bond Strength	Flexural Strength
Product A	H	H	H
Product B	**H**	**H**	**H**
Product C	H	M	H
Product D	H	H	M
Product E	**M**	**H**	**M**
Product F	M	M	M
Product G	**M**	**L**	**M**
Product H	L	M	M
Product I	M	L	L
Product J	L	L	L
Product K	**L**	**L**	**L**

Materials were ranked according to relative compressive strength, slant shear bond strength and flexural strength. Four materials that represent a broad range of performance were selected for further study. The selected materials included Rapid Set DOT Mix, 10-61 Rapid Set, Futura 15 and PaveMend 15.0.

Down-Selected Materials

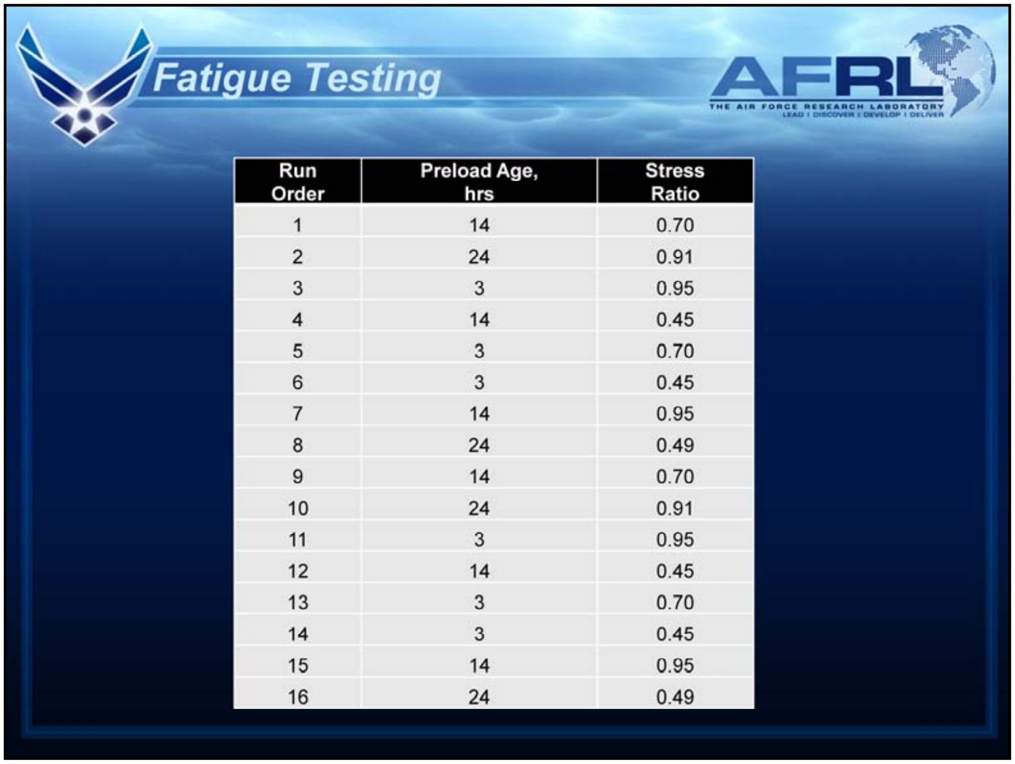
Material	Comp-ressive Strength	Slant Shear Bond Strength	Flexural Strength	Modulus of Elasticity	Coeef. of Linear Thermal Expansion	Shrinkage
Product B	H	H	H	M	M	M
Product E	M	H	M	H	L	M
Product G	M	L	M	L	M	H
Product K	L	L	L	L	H	Expansive

This a qualitative summary of the results from the down-selected materials. Modeling of the effects of these material properties is required to understand how these would effect the performance of the spall repair under environmental and mechanical loading.

Temperature Sensitivity

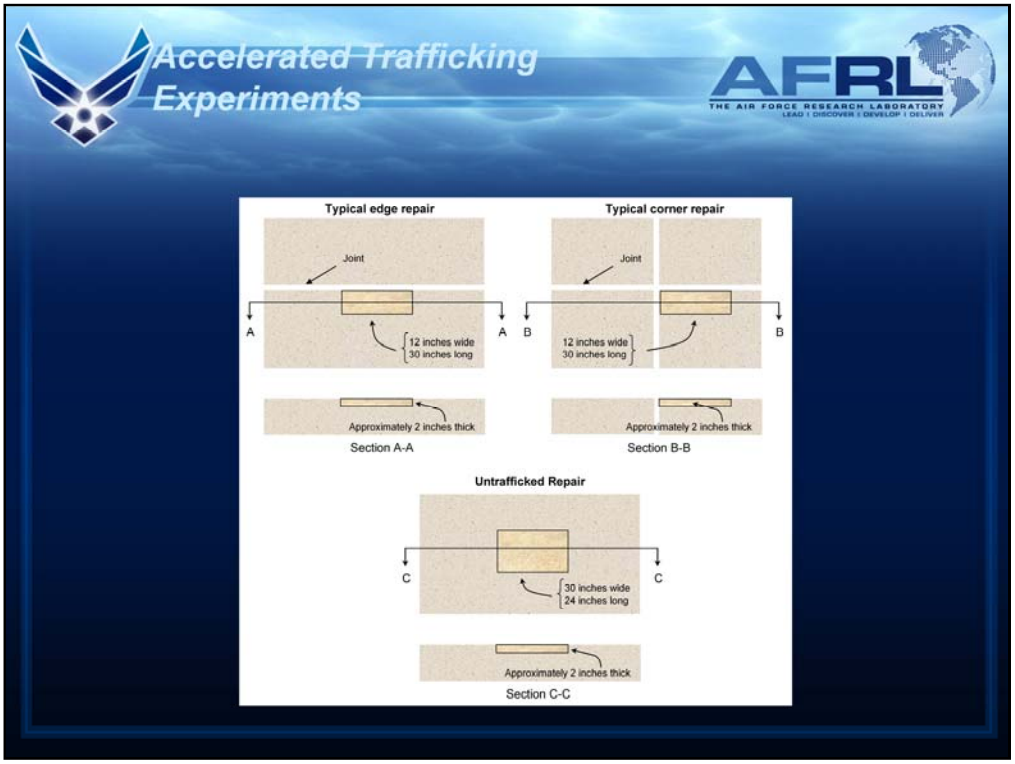
Run Order	Age, hrs	Storage Temp., deg F	Mix Temp., deg F
1	13	77	77
2	15.5	100	100
3	24	77	77
4	24	100	40
5	12	40	77
6	1.5	77	100
7	24	40	100
8	1.5	40	40
9	10.5	77	40
10	24	40	40
11	1.5	100	77
12	1.5	40	100
13	13	77	77
14	15.5	100	100
15	24	77	77
16	24	100	40
17	12	40	77
18	1.5	77	100
19	24	40	100
20	1.5	40	40

In order to measure the affects of extreme temperatures, samples of spall repair materials will be prepared and stored at two ambient temperatures, 40 degrees F and 100 degrees F, until the appropriate time interval for each strength test. Mix materials will be stored at the same ambient temperature, 40 degrees F and 100 degrees F, and at possibly at room temperature, approximately 77 degrees F, prior to mixing to represent materials. This slide presents the experimental design for this portion of the research.

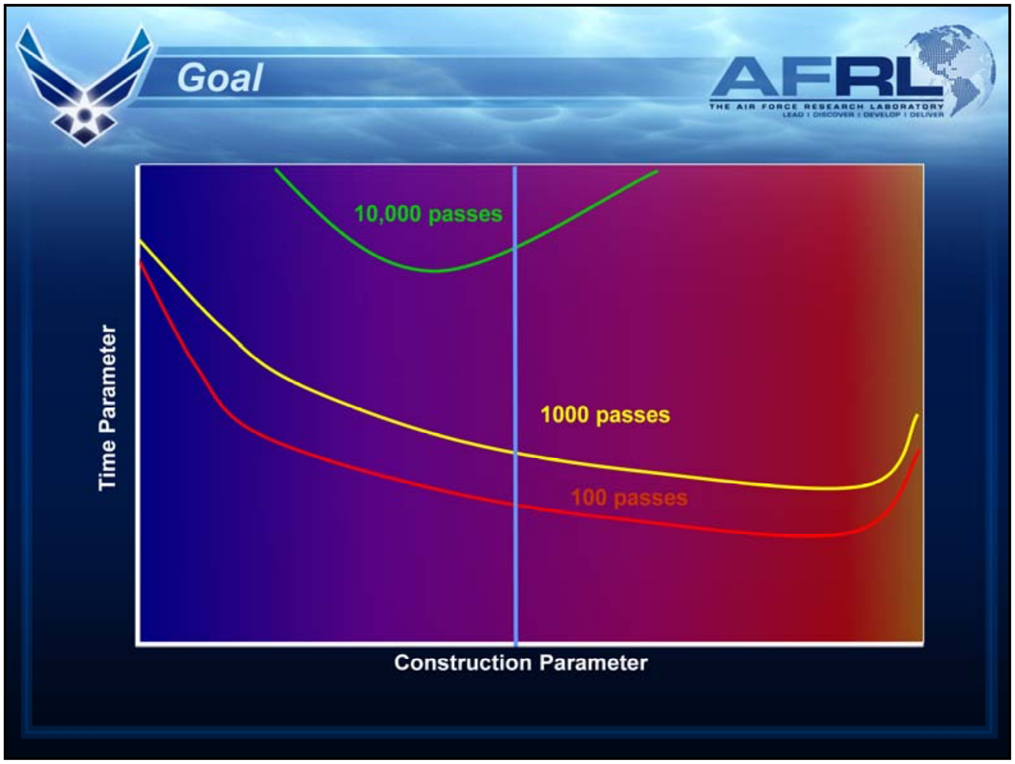


Run Order	Preload Age, hrs	Stress Ratio
1	14	0.70
2	24	0.91
3	3	0.95
4	14	0.45
5	3	0.70
6	3	0.45
7	14	0.95
8	24	0.49
9	14	0.70
10	24	0.91
11	3	0.95
12	14	0.45
13	3	0.70
14	3	0.45
15	14	0.95
16	24	0.49

Fatigue testing will be performed on the four down-selected spall repair materials at room temperature. Induce bond failure by repeated slant shear loading of a sample prepared with typical concrete and a spall repair material. The fatigue test matrix is given in Table 3. Each sample will be fatigue tested after all strength gain has developed, that is, after 28 days or more. Stress levels will be based upon the ultimate slant shear bond strength at an age of 28 days determined at room temperature. There are four materials and 16 test conditions per material for a total of 64 fatigue tests.



The four down-selected will be trafficked with the F-15 load cart. Two spall repair types, an edge repair and a corner repair, will be constructed and trafficked. A total of three spall repairs will be prepared for each of the selected materials. The edge and corner spall repairs to be trafficked will be approximately 12 inches wide, 30 inches long and 2 inches deep as shown here. The untrafficked repair will be approximately 24 inches wide, 30 inches long and 2 inches deep.



This slide illustrates what a notional performance model might look like for a spall repair material. Spall repair performance will depend upon a construction parameters and time parameters. An example of a construction parameter would be the temperature at time of placement. An example of a time parameter would be the cure time a first loading. The resulting performance model would allow users to estimate the number of passes of a selected aircraft of interest before a limit (unsatisfactory performance) state would be achieved for the repair.


Questions?
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